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Dependence of the descent speed of the drilling tool on the stability of the wellbore

Zależność prędkości zapuszczania narzędzia wiertniczego od stabilności odwiertu

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ABSTRACT: In the context of the constant development of the oil and gas industry, special attention is paid to drilling wells to great depths. This study focuses on complex aspects related to the drilling rate and wellbore stability, examining the key factors affecting the efficiency of drilling operations. The article emphasizes the importance of integrating innovative technologies to overcome technical obstacles encountered when drilling at significant depths Drilling deep wells is a multifaceted task that requires a comprehensive approach, including careful analysis and selection of equipment, as well as the use of advanced technologies. The article examines in detail important aspects, including geological conditions that directly impact the choice of technologies and equipment for drilling deep wells. Particular attention is given to wellbore stability, which is critical to the safety and efficiency of drilling operations. Strategies for controlling lateral pressure, preventing well deviations, assessing geological conditions, and using suitable drilling fluids are explored. The challenges of drilling in turbulent conditions necessitate a unique approach to control parameters, including mud pressure, flow rate, and fluid viscosity. The role of real-time monitoring systems and the use of additives are highlighted as key elements for optimizing drilling parameters. The research's analytical approach incorporates pressure balance equations and kinematic principles to understand the movement of drilling tools in turbulent wellbores, thereby improving drilling accuracy and safety. In conclusion, the article emphasizes the need for a comprehensive approach, including understanding geological conditions, equipment selection, and the application of modern technologies to address wellbore stability issues and enhance drilling efficiency. This study provides a valuable contribution to the development of methodologies and strategies aimed at improving the safety and efficiency of drilling operations in the oil and gas industry.

Key words: drilling, wellbore stability, pressure balance, descent speeds, winch power, lifting capacity, rope, analytical approach.

STRESZCZENIE: W kontekście nieustannego rozwoju przemysłu naftowego i gazowego, szczególną uwagę zwraca się na wiercenie odwiertów na dużych głębokościach. W niniejszej pracy skupiono się na złożonych aspektach związanych z prędkością wiercenia oraz stabilnością odwiertu, analizując kluczowe czynniki wpływające na wydajność operacji wiertniczych. Artykuł podkreśla znaczenie integracji innowacyjnych technologii w rozwiązywaniu przeszkód technicznych napotykanych podczas wiercenia na znacznych głębokościach. Wiercenie głębokich odwiertów to wieloaspektowe zadanie wymagające kompleksowego podejścia, w tym dokładnej analizy i doboru sprzętu, a także wykorzystania zaawansowanych technologii. W artykule szczegółowo omówiono istotne aspekty, w tym warunki geologiczne, które bezpośrednio wpływają na dobór technologii i sprzętu do wiercenia głębokich odwiertów. Szczególną uwagę poświęcono stabilności otworu wiertniczego, która ma kluczowe znaczenie dla bezpieczeństwa i efektywności operacji wiertniczych. Przeanalizowano strategie kontrolowania ciśnienia bocznego, zapobiegania odchyleniom odwiertu, oceny warunków geologicznych i stosowania odpowiednich płynów wiertniczych. Podkreślono rolę systemów monitorowania w czasie rzeczywistym i stosowania dodatków jako kluczowych elementów optymalizacji parametrów wiercenia. Analityczne podejście badawcze obejmuje równania równowagi ciśnień oraz zasady kinematyki w celu poznania ruchu narzędzi wiertniczych w odwiertach charakteryzujących się przepływem turbulentnym, poprawiając tym samym dokładność i bezpieczeństwo wiercenia. Podsumowując, artykuł podkreśla potrzebę kompleksowego podejścia, w tym zbadania warunków geologicznych, doboru sprzętu i zastosowania nowoczesnych technologii w celu rozwiązania kwestii stabilności odwiertu i zwiększenia wydajności wiercenia. Badanie to stanowi cenny wkład w rozwój metodologii i strategii mających na celu poprawę bezpieczeństwa i wydajności operacji wiertniczych w przemyśle naftowym i gazowym.

Słowa kluczowe: wiercenie, stabilność odwiertu, równowaga ciśnień, prędkości zapuszczania, moc wciągarki, nośność, lina, podejście analityczne.

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Introduction

In today's oil and gas industry, drilling deep wells is a complex and multifaceted process that requires an integrated approach to managing drilling operations, maintaining wellbore stability, and optimizing fluid flow. Efficient drilling not only improves productivity but also ensures safe operations, which is especially important when working in extreme geological and operational conditions (Bulatov, 1981; Basarygin et al., 2001; Guliyev and Shirinov, 2009; Akhundov and Hasanov, 2015).

The challenges of drilling deep wells arise from a number of critical factors, including the physical and mechanical properties of the drill string, geological conditions, and the characteristics of the drilling mud and fluid. Key challenges include ensuring wellbore stability, mitigating risks associated with hydraulic fracturing, and adapting drilling technologies to changing conditions.

This article reviews the basic principles and techniques used to improve the efficiency and safety of drilling operations. In particular, the relationship between the descent speed of the drilling tool and the stability of the wellbore will be explored, along with the role of innovative technologies in solving problems associated with drilling at significant depths. The influence of geological conditions on the choice of equipment and technologies, as well as drilling management strategies to minimize risks and optimize the drilling process, will also be discussed in detail.

Given that drilling in turbulent conditions presents unique challenges, special attention will be paid to managing mud pressure, flow rate, fluid viscosity, and the use of additives. A key role here is played by real-time monitoring systems, which enable the optimization of drilling parameters and adaptation to dynamic conditions in the well.

Finally, an analytical approach to drilling will be examined, incorporating calculations of pressure balance equations and kinematic principles to gain a deep understanding of the movement of drilling tools in turbulent conditions. This research will help determine the most effective and safe drilling methods to ensure stable wellbores and prevent issues such as hydraulic fracturing or wellbore wall collapse.

A common theme runs through all aspects of this research: drilling deep wells requires an integrated, multi-level approach that includes both traditional methods and innovative technologies. Each aspect of the drilling process presents unique challenges and decisions that require careful analysis and strategic planning.

The speed of tripping operations in well drilling depends on many factors, including not only the technical characteristics of the equipment, but also various other aspects. Below is an overview of some of those factors.

Setting the issue

Advancements in deep-well drilling: technologies, challenges, and solutions

Drilling wells to greater depths is a crucial strategy in the ever-evolving field of oil and gas extraction. This article explores the intricate relationship between the descent speed of drilling tools and the stability of the wellbore. It delves into various factors affecting the efficiency of drilling operations and introduces innovative technologies designed to address challenges associated with drilling at significant depths.

Trip speed factors in well drilling depend not only on the technical characteristics of equipment, such as the draw works, but also on various other aspects, as shown in Figure 1.

Figure 1. Conceptual diagram of descent speed in well drilling
Rysunek 1. Schemat koncepcyjny prędkości zapuszczania podczas wiercenia otworów

The image displays a conceptual diagram with five nodes, each representing a concept related to well management and stability in oil and gas context. The explanations what each node stands for are provided below.

Wellbore stability

The central node, depicted in orange, emphasizing the primary focus. Wellbore stability refers to the importance of maintaining the structural integrity of the wellbore during drilling and production operations.

Wellbore stability while drilling and retrieving tools is a critical aspect of the drilling process. It relates to how a well maintains its shape and structure under various impacts, such as the rotation of the drilling tool, the injection of drilling fluid, and the lifting of tools.

This includes several aspects:
1. Controlling lateral pressure: Maintaining proper lateral pressure is essential to prevent the collapse of well walls. Lateral pressure is controlled by adjusting drilling fluid pressure, selecting the correct weight of the drill string, and, if necessary, using additional materials.
2. Preventing wellbore deviation: Wellbore deviation can cause issues such as lost tools, difficulties with geophysical measurements, and ineffective drilling. Proper design and use of drilling tools, along with directional drilling techniques, help prevent hole deviation.
3. Assessing geological conditions: Understanding geological characteristics is vital for predicting possible stability issues. Different geological formations may require different strategies to maintain stability.
4. Using suitable drilling fluids: Drilling fluid properties such as viscosity, density, and chemical composition can affect hole stability. They must be adjusted according to geological conditions.
5. Monitoring and responding to changes: Regular monitoring of drilling parameters such as bit weight, mud pressure, and hole depth, allows operators to quickly respond to changing conditions and prevent potential problems.

Wellbore stability is a key factor in ensuring drilling safety and efficiency. Its control requires careful planning, monitoring, and responding to changes in drilling conditions.

Driving wireline strength

The grey node highlights the importance of wireline strength – the cable used to lower equipment or measurement devices into the well.

The wireline is a critical element in raising and lowering drilling tools and other equipment. Its strength, durability, and overall reliability directly impact the safety and efficiency of all drilling operations. Key considerations include:
1. Strength: The wireline must be strong enough to support the weight of the drilling tool and other equipment as it is raised and lowered. Its strength depends on material, design, and diameter.
2. Wear resistance: During the lifting and lowering process, the rope is subject to wear and tear. Wear protection is important to prevent damage that could reduce its strength and durability. Regular inspection and maintenance can identify signs of wear.
3. Reliability: Wireline reliability is critical to preventing downhole accidents. An unreliable wireline can lead to lost drilling tools, equipment damage, or even safety incidents.
4. Corrosion resistance: Running rope is often exposed to moisture and chemically aggressive environments that can cause corrosion. Materials with high corrosion resistance are important to maintain rope reliability.
5. Flexibility: Wireline flexibility is important to ensure proper guidance and lifting of the equipment in the well. Flexible wireline provides better maneuverability and control during the drilling process.
6. Marking and identification: Proper marking and identification of the wireline facilitate its condition management and monitoring, as well as planning replacements based on wear or service life.

Safety, reliability, and drilling efficiency largely depend on the quality and condition of the wireline. Regular maintenance, inspections, and adherence to safety standards are essential to ensure optimal performance of the wireline under drilling conditions.

Column resistance to external collapsing pressure

The yellow node highlights the importance of the well's structural column ability to resist external pressures that could cause it to collapse.

When a drill string is positioned inside a borehole, it must withstand various geological conditions, including changes in pressure, temperature, and rock composition. Resilience and resistance to these conditions are essential for successful operation.

Methods for ensuring column stability and resistance to external compressive pressure:
1. Use of suitable materials: Selecting appropriate materials for the drill string is crucial for its stability. Durable materials that are resistant to soil and chemical factors enhance drilling durability and efficiency.
2. Hydraulic balancing: Proper control of drilling fluid pressure creates a hydraulic barrier, preventing well collapse due to external pressure. This also stabilizes the rock structure surrounding the drill string.
3. Use of casing pipes: Casing strengthens well walls, preventing their deformation under formation pressure. It also helps prevent wall collapse and protects the drill string from external influences.
4. Temperature control: High well temperatures inside the well necessitate the use materials and technologies resistant to thermal influences. This prevents deformation and strength loss in the drill string.
5. Geological studies: Comprehensive geological studies help anticipate potential challenges and tailor drilling

strategies to specific geological conditions, ensuring drill string stability.

6. Modeling and simulation: Mathematical models and simulations enable prediction of drill string behavior under various conditions, facilitating design optimization and selection of drilling parameters for enhanced stability.
7. Personnel training and maintenance: Trained personnel play a key role in maintaining the stability of the drill string. Regular maintenance and inspections help identify potential problems and prevent accidents.

Successful drilling across diverse geological conditions requires not only the use of modern equipment, but also a comprehensive understanding and management of the operating conditions inside the well.

The technical characteristics of drill draw works significantly influence the efficiency and speed of tripping operations during well drilling. Let's consider in more detail the effect of various factors (Figure 2).

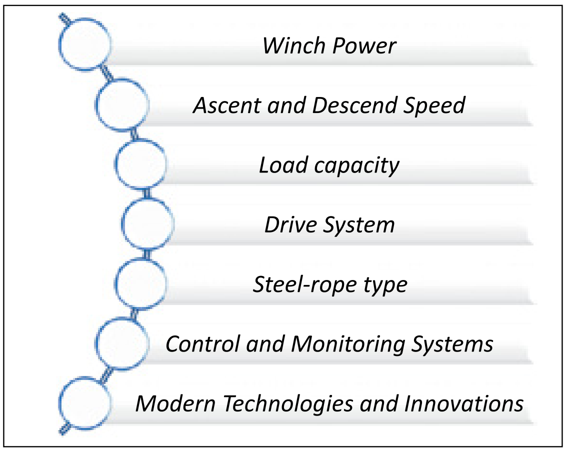

Figure 2. Key factors of tripping operations during well drilling
Rysunek 2. Kluczowe czynniki związane z operacjami wyciągania i zapuszczania podczas wiercenia otworów

The winch's high power enables more efficient lifting and lowering of drilling equipment. This is particularly important when handling heavy drilling tools and rapid responses to changing well conditions are required.

Fast ascent and descent speeds reduce cycle times, which is important for increasing drilling productivity. However, safe speed limits must be taken into account in order to prevent accidents.

The lifting *capacity* of a winch determines the weight of equipment it can safely lift and hold. This is important to ensure safe and efficient lifting of various sizes of drilling tools.

An efficient winch *drive system*, whether hydraulic or electric, impacts the stability and accuracy of lifting and lowering equipment. Modern drive systems provide more precise control and response.

The use of high-strength *running ropes* with adequate wear resistance is essential for longevity and safe operations. Different types of wire ropes can be optimized to suit specific drilling conditions.

Integrated *control and monitoring* systems enable operators to observe and monitor winch performance in real time, enhancing the accuracy and control of operations.

The adoption of modern technologies, such as automated control systems, load sensors, anti-overload systems, and other innovations, can significantly improve the efficiency and safety of drilling.

The technical specifications of the winch must align with the dimensions and weights of the drilling tools and equipment in use. These parameters are closely interconnected and must be coordinated to ensure optimal performance and safety during the drilling process.

In the context of ongoing technological progress and the rapid development of the oil and gas industry, increasing well-drilling depths has become an integral part of strategies aimed at increasing hydrocarbon production. However, greater depths introduce a range of challenges that require modern solutions and meticulous planning.

Let's take a look at a few key aspects to consider when increasing the depth of the well:

- **Technological Design**

Increasing depth requires not only more powerful drilling equipment but also innovative technologies. The use of modern automation and remote-control algorithms can improve the efficiency of operations and reduce risks.

Various innovative technologies can be employed to increase drilling depth and improve operational efficiency. Examples include:

a) *Unmanned drilling rigs*: The use of unmanned drilling rigs with automated control systems can significantly improve the efficiency and safety of drilling at great depths. These rigs can be equipped with sensors and monitoring systems for more precise process control.
b) *Geometric modeling systems*: The use of modern geometric modeling systems and data processing algorithms makes it possible to more accurately predict rock structure at depth and optimize drilling plans to minimize risks.
c) *Intelligent drilling systems*: The development and implementation of artificial intelligence algorithms to analyze data from drilling rigs can improve both the accuracy and speed of the drilling process. These systems can adjust drilling parameters in real time, accounting for changes in the soil.
d) *Nanotechnology in drilling*: The use of nanomaterials in the drilling process can improve the rate of penetration into the soil and reduce wear on drilling tools. For example,

nanoparticles or nanotubes can be added to drilling fluids to improve their properties.

e) *Wireless communication technologies and Internet of Things (IoT)*: Monitoring and communication systems based on IoT technologies can provide operators with real-time information on rig status and well conditions, enabling them to quickly respond to changes.

f) *Geophysical techniques and investigations*: The use of modern geophysical techniques, such as seismic tomography, can help more accurately determine soil structure and better prepare for drilling at greater depths.

The integration of these technologies can significantly improve the efficiency and safety of the drilling process at significant depths.

- **Gravitational Influences**

Developing drilling systems that are resistant to gravity forces is becoming an important component. The use of modern materials and engineering solutions helps address additional loads during ascent and descent.

The development of drilling systems that can operate effectively under gravity is an important area of innovation in the oil and gas industry. Several technological and engineering solutions aimed at improving the stability of drilling systems during ascent and descent include:

a) *Use of composite materials*: The use of lightweight, durable and corrosion-resistant composite materials in the construction of drill pipes, drill heads and other elements helps reduce the weight of equipment while maintaining its strength.

b) *Development of intelligent control systems*: Integration of advanced control systems based on artificial intelligence can allow the drilling system to automatically adjust its position and ascent/descent parameters in real time, taking into account gravitational forces and other factors.

c) *Use of active shock absorbers*: The introduction of active shock absorption systems into drilling systems allows them to compensate for changes in load and vibrations, which contributes to more stable operation in variable gravitational conditions.

d) *Development of specialized drill bits*: Innovative drill bit designs, equipped with special systems to better cope with gravitational forces, can significantly improve the productivity and longevity of drilling equipment.

e) *Improved Lifting and Handling Systems*: The use of advanced lifting systems, including hydraulic and electrical technologies, can enhance the lifting process of drilling equipment by reducing the impact of gravitational forces on the system.

f) *Innovative Friction Reduction Technologies*: The development of new lubricants and friction reduction systems helps reduce wear and increase the efficiency of drilling systems in high-gravity environments.

Integrating these technologies can significantly improve the stability and performance of drilling systems when operating in variable gravity environments.

- **Infrastructure and Materials**

Increasing drilling depths require not only stronger drilling equipment but also improved infrastructure to support these operations. Here are a few aspects that can be improved using the latest composite materials and construction technologies:

a) *Drill pipes and tubes*: The use of durable composite materials such as carbon fiber or reinforced composites can make drill pipes lighter, stronger, and more corrosion resistant, which is crucial when working at great depths.

b) Lifting and hndling equipment: The use of composite materials in lifting and handling systems can reduce weight and increase strength, allowing for more efficient operation at greater depths.

c) *Drill bits*: The development of drill bits and bits made from new composite materials with improved wear resistance can increase tool life and reduce the need for regular replacements.

d) *Structural infrastructure elements*: The use of composite materials for the construction and maintenance of drilling rigs, drilling platforms, and other structural infrastructure elements can improve their stability, strength, and durability.

e) *Control and monitoring systems*: The integration of advanced composite materials with control and monitoring systems creates lightweight, durable sensors that can withstand high pressure and temperature at depth.

f) *Piping and pumps*: The use of composite materials in piping and pump components can improve their resistance to harsh environments and wear.

Integrating advanced composite materials and technologies into drilling operations infrastructure can lead to more reliable, efficient, and durable systems for operating at significant depths.

- **Prevention and Maintenance**

Developed monitoring and diagnostic systems help prevent problems inside the well. Regular maintenance using probes and sensors reduces downtime and increases overall efficiency.

Developed monitoring and diagnostic systems play a key role in ensuring drilling reliability and efficiency. The use of modern technologies in this area allows for quick identification of potential problems, prevention of accidents, and optimization of well operation processes. Here are some examples of how monitoring and diagnostic systems help improve efficiency:

a) *Early detection of problems*: The use of sensors makes it possible to monitor various parameters in real time, such as pressure, temperature, vibration, and fluid composition. Early detection of abnormalities allows action to be taken before the problem becomes critical.
b) *Equipment monitoring systems*: Advanced monitoring systems can monitor the condition of drilling equipment, including motors, pumps, drill pipes and other components. This helps prevent breakdowns and optimize resource consumption.
c) *Fluid composition monitoring*: Monitoring the chemical composition of drilling fluids allows for a prompt response to changes in the formation and effective adjustments to chemistry to optimize drilling processes.
d) *Data measurement and recording systems*: The use of systems that automatically capture and archive data allows for subsequent analysis of processes, identification of trends, and improvement of drilling strategies.
e) Automated diagnostic systems: The use of artificial intelligence and machine learning algorithms allows the creation of automated diagnostic systems that can detect anomalies and predict potential problems based on the analysis of accumulated data.
f) *Remote monitoring and control*: The use of communications technology enables remote well monitoring and control, increasing responsiveness to changes and reducing downtime.

Advanced monitoring and diagnostic systems not only help prevent problems but also improve overall drilling efficiency by reducing downtime and optimizing production processes.

- **Energy efficiency**

To achieve energy efficiency and optimize energy consumption at great depths, various innovative technologies are used:
a) *High efficiency pumping systems* – development of pumping systems using high-efficiency pumps and motors designed to minimize energy consumption while delivering high performance. Variable speed systems are also being introduced to adjust fluid flow depending on current conditions in the well.
b) *Automatic pressure control systems* – the use of modern automatic pressure control systems that optimize fluid supply processes depending on current requirements. This reduces excess pressure and thus decreased the energy consumption of pumping systems.
c) *Intelligent controllers and sensors* – implementation of intelligent controllers operating based on data from sensors to respond to changes in well conditions. This allows dynamic adaptation of [umping system operations, minimizing energy costs.
d) *Energy-saving materials*– the use of special energy-saving materials in the design of pumps and pipelines reduces heat loss and optimize the thermal characteristics of the system.
e) Energy recovery systems – integration of energy recovery systems that can convert excess pressure or kinetic energy released during lifting by a pump back into electrical energy. This helps reduce overall system power consumption.
f) *Data monitoring and analytics* – creating monitoring and analytics systems that allow constant monitoring of energy consumption by pumping systems, identify potential problems, and optimize processes based on the data obtained.

These innovative energy-efficiency technologies not only reduce operating costs but also reduce the negative impact on the environment, making deep drilling a more sustainable and efficient process.

- **Training and Qualification**

An important component of successful drilling at great depths is the qualifications and competence of personnel. Training drilling professionals using modern technologies is becoming a key factor to ensure safety, efficiency, and the effective use of innovations. Here are a few aspects of training that may be important:
a) *Technical skills* – training of personnel in the operation of modern drilling equipment and mastering the latest technologies and tools. This may include hands-on work with high-tech equipment and automation systems.
b) *Safety and ecology* – mastering modern safety standards and environmental principles associated with drilling at great depths. This is important to prevent accidents, minimize environmental impact, and comply with legislation.
c) *Engineering solutions and working with data* – training in working with data used in engineering calculations and decision-making. This may include training in modeling programs, geographic information systems, data analytics, and other technologies.
d) *Control and monitoring systems* – understanding and training in the use of control and monitoring systems that are used to monitor drilling parameters, analyze data, and make operational decisions.
e) *Modern Tteaching methods* – use of modern teaching methods such as virtual simulators, interactive courses and online resources. This allows drilling specialists to effectively learn and apply knowledge in practice.
f) *Teamwork and communication* – development of teamwork and effective communication skills within the drilling crew. This is important for synchronizing actions and preventing possible problems.

Training that incorporates modern technologies not only improves the skill level of drilling specialists but also helps them effectively apply new methods and innovative technologies in their work, which ultimately contributes to more successful and productive drilling operations at great depths.

The modern approach to increasing well depth includes the integration of advanced technologies, resilience to changing conditions, and an emphasis on energy efficiency to not only meet challenges but also improve the overall productivity of oil and gas operations.

Different types of soil and rock require different drilling techniques and can speed up or slow down the process depending on their composition and structure.

Solving the challenges of drilling deep wells: equipment, technology, and geological considerations

Drilling deep wells presents a unique set of challenges that demand careful analysis, strategic equipment selection, and the integration of advanced technologies. This article explores critical factors influencing the choice of drawworks and drilling technology for deep boreholes, along with the geological conditions encountered by the drill string within the well.

The size of the well and the drilling equipment used are critical factors influencing the choice of drawworks and drilling technology. Additional aspects to consider when addressing this issue are presented in Table 1.

All of these factors highlight the importance of careful analysis and selection of equipment, as well as the use of advanced technology to ensure safety and efficiency when working with deep wells. When the drill string is located inside a well, it encounters various geological conditions, which can vary significantly depending on the depth and specific geological formation. Major factors faced by the drill string include:

- **Pressure Change**

  Pressure may vary depending on the depth of the well and geological formations. At greater depths, pressure can be significantly higher, which affects the structure and behavior of drilling equipment.
- **Temperature Change**

  The temperature inside a well can vary significantly with depth. At greater depths, higher temperatures affect drilling equipment performance and require the use of materials capable of withstanding high temperatures.
- **Soil and Rock Composition**

  Geological formations can range from soft soils to extremely hard rocks, necessitating different types of drill bits and tools to overcome diverse conditions effectively.
- **Water and Other Liquids**

  The presence of water, oil, gas, and other liquids inside a well can influence the drilling process. Specialized techniques and equipment help manage and extract these fluids.
- **Loss of Circulation**

  During drilling, loss of circulation of drilling fluid may occur, especially in cases of rock rupture. Monitoring and controlling circulation are crucial to prevent complications.
- **Sedimentary Rocks**

  Encountering sedimentary rocks can pose various problem during drilling, such as the issues with the borehole walls stability or passage of the drilling tool.
- **Geological Features**

  Fractures, cavities and other geological features can affect drilling performance, requiring appropriate technology for effective mitigation.

Table 1. Additional aspects to consider
Tabela 1. Dodatkowe aspekty, jakie należy uwzględnić

Additional Aspects	Description
Winch Capacity	Larger borehole diameters and the use of bigger drilling tools necessitate a powerful winch with high lifting capacity.
Load Management Systems	To handle heavy tools and large diameters; load management systems prevent overloads, ensuring safe lifting and lowering movements.
Winch Drive Power	Increasing hole size may require a more potent winch drive system for efficient hoisting and lowering operations.
Drilling Tool Resistance	Larger tools in larger diameter holes encounter greater soil and rock resistance, demanding additional power to maintain stable operation.
Overcoming Additional Resistances	Varying soil and rock characteristics may demand sophisticated technologies, such as large-diameter tools or inclination control systems.
Requirements for Running Ropes	Larger tools may require stronger and thicker hoisting ropes for safe and efficient lifting.
Motion Control Technologies	Deeper wells necessitate precise motion control technologies to avoid oscillations and ensure stable lifting and lowering.
Innovations in Drilling	Modern innovations like automation systems and geostationary control systems provide efficient solutions for drilling deep wells.

All of these factors require drilling professionals to use the appropriate equipment, technologies, and drilling strategies to operate effectively and safely in varying geological conditions.

The wireline is a critical element in raising and lowering drilling tools and other equipment in a well. The running rope must be strong enough to support the weight of the drilling tool and other equipment as it is raised and lowered. Its strength depends on material, design, and diameter. During lifting and lowering, the rope is subject to wear and tear. Wear protection is important to prevent damage that could reduce its strength and durability. Regular inspection and maintenance help identify signs of wear. The reliability of the wireline is critical to preventing accidents during well operations. A loose rope can result in lost drilling tools and equipment damage.

The running rope is often exposed to moisture and chemically aggressive environments, which can cause corrosion. Using materials with high corrosion resistance is essential to maintaining rope reliability.

The flexibility of the rope is important to ensure proper guidance and lifting of the equipment in the well. A flexible rope provides better maneuverability and control during the drilling process.

Safety, reliability, and drilling efficiency largely depend on the quality and condition of the wire rope. Regular maintenance, inspections, and compliance with safety standards are crucial to ensuring the wireline performs optimally in drilling conditions.

The resistance of drill strings to external crushing pressure is an important aspect of geotechnics and drilling, particularly when working in wells. Resistance to crushing pressure depends on various factors, including geological conditions and drill pipe characteristics.

When the string is inside the well, it is subject to external pressure from the surrounding rock, which can cause the drill pipes to compress. To determine the resistance to crushing pressure, the following aspects are taken into account:

- **Geological Conditions**

Different geological formations exhibit varying resistance to crushing pressure. For example, soft rocks or shale formations may have low resistance, while hard rocks provide greater resistance.

- **Characteristics of Drill Pipes**

The material and design of drill pipes influence their resistance to crushing pressure. Durable materials and special designs can enhance resistance.

- **Geometry and Dimensions of the Column**

The diameter and thickness of the drill pipes are also important. Larger diameters and/or thicker walls can increase compression resistance.

- **Drilling Fluid Pressure**

The pressure of the drilling fluid inside the drill pipes can create additional internal pressure to compensate for the external crushing pressure.

- **Well Casing Methods**

The use of cementation methods, such as casing, can strengthen the well walls and increase compressive strength.

Assessing crush resistance is an important part of drilling design. Engineers consider all of these factors when selecting drilling equipment and strategies for a particular well.

Methods for ensuring the stability and resistance of columns to external compressive pressure:

a) *Use of suitable materials*: The choice of materials for the drill string plays an important role in ensuring its stability. Durable materials that are resistant to soil and chemical factors contribute to the durability and efficiency of drilling.
b) *Hydraulic balancing*: Proper control of drilling fluid pressure helps create a hydraulic barrier, preventing wellbore collapse under external pressure. It also helps stabilize the rock structure around the drill string.
c) *Use of casing*: Casing reinforces well walls, preventing deformation under formation pressure. It also helps avoid wall collapse and protects the drill string from external influences.
d) *Temperature control*: In high-temperature wells, materials and technologies resistant to thermal influences are essential. This prevents deformation and loss of strength in the drill string.
e) *Geological studies*: Comprehensive geological studies help anticipate possible difficulties and tailor drilling strategies to specific geological conditions, ensuring drill string stability.
f) *Modeling and simulation*: The use of mathematical models and simulations makes it possible to predict the behavior of the drill string under various conditions. This makes it easier to optimize the design and selection of drilling parameters to ensure stability.

Successful drilling in diverse geological conditions requires not only the use of modern equipment, but also a comprehensive understanding and management of the operating conditions inside the well.

Different soil types and geological conditions can result in different well behaviors such as wall failures, bottlenecks, compressions, differential pressures, etc. These factors can slow down or complicate operations.

Well events and their impact on drilling operations:

a) *Borehole wall collapses*: Unstable soils can cause borehole wall collapse, slowing the drilling process, risking equipment loss, and creating obstacles for lowering and retrieving drilling tools.

b) *Bottlenecks and restrictions*: Borehole bottlenecks or restrictions can also complicate drilling and equipment lifting. This requires the use of specialized drilling tools or techniques to navigate narrow areas.
c) *Compression and deformation of the walls*: Formation pressure can cause compression and deformation of the well walls. This creates a risk of losing drill string stability and requires the use of wellbore strengthening methods.
d) *Differential pressures*: Pressure differences in different areas of the well can cause problems such as loss of drilling fluid circulation or even hydraulic fracturing. Pressure management and the use of appropriate drilling fluids are important aspects of minimizing these problems.
e) *Clay and loam formations*: Clay and loam formations can cause additional difficulties due to their plasticity and tendency to trap the drilling tool. The use of special drilling fluid additives or the use of tools with improved flotation can help overcome these problems.
f) *Avoiding contamination*: Encountering different rock layers can lead to contamination of the drilling fluid, which in turn can affect drilling efficiency. Controlling drilling fluid properties and using screens and casing help minimize this risk.
g) *Hard-to-reach areas*: Operations in hard-to-reach areas, such as overlapping soil layers, may require special techniques and tools to ensure safe and efficient drilling.

Managing and overcoming these well events requires careful analysis of geological data, the application of appropriate drilling techniques, and the use of specialized equipment. These are important aspects to ensure successful and safe drilling operations.

Effectively managing drilling fluid pressure and flow rate is crucial for maintaining stability and preventing potential problems such as rock failure, shaft collapse, and other adverse events. Effective control of drilling fluid pressure and flow rate is a key component of successful drilling operations, ensuring a safe, stable, and efficient drilling process.

Ensuring drilling efficiency: managing drawworks, wellbore stability, and fluid flow

Ensuring efficient and safe tripping operations requires a comprehensive approach, including careful planning, the use of suitable equipment, and continuous monitoring of well conditions. When determining the operating parameters of a drawworks brake, many factors must be taken into account, including the likelihood of hydraulic fracturing. Hydraulic fracturing can occur when drilling fluid pressure and flow rates are not properly managed, potentially leading to wellbore stability problems and even formation failure (Kerimov and Aliyev, 1981; Aliyev, 2010, 2023).

Below are some aspects that should be considered when determining the operating parameters of the drawworks brake, taking into account the likelihood of hydraulic fracturing.

Mud pressure control: It is crucial to carefully control the pressure inside the well to avoid exceeding acceptable limits, which could lead to hydraulic fracturing.

Monitoring geological conditions: Understanding geological conditions in the drilling area helps predict potential hydraulic fracturing risks. For example, known weak areas or cracks may require special attention.

Application of safe drilling technologies: the use of modern technologies and drilling methods designed to minimize the risk of hydraulic fracturing.

Personnel training: Trained personnel familiar with drilling safety principles and monitoring parameters can effectively respond to potential threats and prevent accidents.

Managing drawworks brake parameters must include not only technical aspects but also careful planning, monitoring, and personnel training to ensure safe and efficient drilling while accounting for hydraulic fracturing risks considering the constraint imposed by wellbore stability.

The constraint imposed by wellbore stability is, of course, a critical factor in drilling. Wellbore stability refers to the ability of the wellbore walls to maintain their integrity and support surrounding formations during drilling and other downhole operations. Wellbore stability is influenced by geological, mechanical, and hydraulic factors. Key aspects associated with wellbore stability constraints include:

Geological conditions: Different rocks have different degrees of stability. Understanding subsurface geological characteristics, such as rock types, formations, and the presence of faults or fractures, is crucial. Unstable formations can lead to wellbore collapse, well enlargement, or other problems.

Drilling fluid properties: The selection and properties of drilling fluid play a critical role in wellbore stability. Drilling fluid helps maintain pressure in the wellbore, cool the drill bit, and transport cuttings to the surface. Proper drilling fluid weight, viscosity, and chemistry are essential to prevent wellbore instability issues such as loss of drilling fluid, shale swelling, or stuck pipe (Ryabchenko, 1990; Ryazanov, 2004).

Wellbore pressure control: Wellbore pressure control is critical. Improper pressure control can lead to fluid influx, blowouts, or wellbore collapse. Monitoring and managing the balance between well and reservoir pressure is essential for stability.

Wellbore enlargement and shale stability: Some formations, especially shales, are prone to instability. Clay formations can swell or flake into the wellbore, causing the well to widen. Good drilling practices, adjustments in drilling fluid chemistry, and the use of stabilizers are used to mitigate shale stability problems.

Casing string design: Casign design and placement also affect wellbore stability. Casing provides support to the wellbore and prevents collapses. Casing design must account for expected bottomhole pressures and reservoir conditions.

Real-time monitoring: Continuous monitoring of well conditions is critical to detect early signs of instability. Measurement while drilling (MWD) and logging while drilling (LWD) technologies provide real-time data, enabling immediate decisions to address stability issues.

Considering the constraints imposed by wellbore stability is important to prevent costly and potentially dangerous issues such as wellbore collapse, stuck pipe, or loss of circulation. A comprehensive understanding of geological conditions and the implementation of proper drilling techniques are vital to maintaining wellbore stability throughout the drilling process.

When lowering a drilling tool into a well, it is necessary to consider not only the pressure balance to avoid hydraulic fracturing but also to ensure the effective opening of the productive horizon. This requires careful monitoring of drilling parameters and selection of optimal operating modes. Key factors to consider include:

Pressure balance: A balance must be maintained between borehole pressure and formation pressure. Excessive pressure can lead to hydraulic fracturing, while insufficient pressure can result in drilling fluid loss in the formation. Therefore, optimal drilling parameters, such as mud pressure, should be selected based on geological conditions and formation characteristics.

Trigger speed control: Controlling the drilling tool speed control is an important aspect of drilling operations, requiring a balance between efficiency and safety. Key considerations for adjusting descent speed include:

Dynamic Pressure Increase:

- *Rapid descent*: rapid descent can cause a dynamic increase in pressure in the well, potentially leading to hydraulic fracturing and other issues. Speed control helps prevent such situations.
- *Slow descent*: Slow descent can reduce the dynamic pressure increase, positively impacting drilling stability. However, excessively slow descent may not be effective.

Tool Jamming:

- *Fast run*: High run speeds can increase the likelihood of the tool jamming, especially in challenging geological conditions, leading to congestion and downtime.
- *Slow release*: Slow release reduces the risk of tool jamming by allowing closer control of the process and avoiding unwanted situations.

Optimization of the Drilling Process:

- *Speed control*: The use of run rate control systems allows engineers to optimize the drilling process in real time by adjusting speed to changing geological conditions.
- *Parameter monitoring*: Continuous monitoring of pressure, temperature, and other parameters in the well is important for controlling the rate of release and enables operators to respond quickly to changes.

Automation Systems:

- *Automated control*: The use of automation systems in drilling operations allows for more accurate and efficient control of the rate of descent. These systems can respond to changing conditions in real time.

Training:

- *Professional training*: Training of drilling personnel is vital for effectively regulating descent rates. Experienced operators can more accurately determine the optimal parameters for specific conditions.

Controlling the rate of descent requires a comprehensive approach that takes into account various aspects of the drilling process and well conditions. This ensures efficient and safe drilling operations.

Quality control of the productive horizon: Monitoring the quality of the productive horizon is a critical stage in the process of drilling wells. This process involves various methods and tools designed to asses and ensure optimal exposure of the productive horizon. Key aspects of this monitoring include:

Use of specialized drilling fluids: Selecting appropriate drilling fluids based on formation properties and drilling objectives plays an important role. For example, adding clay mineral inhibitors can prevent the increase of clay particles in the solution, reducing the likelihood of tool jamming.

Regular monitoring of parameters: Monitoring drilling parameters in real time using modern technologies (for example, measurement while drilling systems) enables quick responses to changes in well conditions and parameters adjustments to ensure optimal performance.

By considering these factors and conducting a thorough analysis of well conditions, it is possible to more effectively manage the drilling process, minimize the risks of hydraulic fracturing, and ensure high-quality penetration of the productive horizon.

Optimizing drilling parameters in challenging conditions

Drilling in turbulent conditions presents unique challenges that require a nuanced approach to parameter control for safe and efficient operations. This article explores the intricacies of managing drilling mud pressure, descent speed, fluid viscosity, additive utilization, and the crucial role of real-time monitoring systems in optimizing drilling parameters amid turbulent fluid flow.

Considering the turbulent regime of fluid flow in the annular space is important for determining optimal drilling parameters to prevent hydraulic fracturing and ensure effective opening of the productive horizon. In a turbulent regime, fluid flow is characterized by random vortices and increased intensity of particle movement. In this context, we will consider several aspects for controlling drilling parameters in turbulent mode.

Drilling mud pressure (DMP)

In turbulent drilling conditions, careful control of mud pressure is key to ensuring safe and efficient operations. It is important to maintain optimal pressure that ensures effective circulation of the fluid, minimizes the risk of loss of circulation, but at the same time helps avoid excessive pressure that could cause hydraulic fracturing. Pressure control in turbulent conditions is a complex task requiring close monitoring, adequate equipment, and highly trained personnel to ensure drilling safety and efficiency.

Lowering speed: The lowering speed of the drilling tool should also be adjustable. High descent speeds can cause vortices and dynamic pressure increases, which are undesirable. A balanced release speed provides better control and prevents unwanted effects.

High viscosity drilling fluids: Using drilling fluids with increased viscosity can be an effective means of controlling fluid flow in turbulent drilling conditions. Increased drilling fluid viscosity can have a positive impact on several aspects of drilling, especially in complex geological formations. Here are a some key benefits:

Preventing loss of circulation

Increased drilling fluid viscosity can help prevent fluid circulation losses in heterogeneous or porous formations. This is especially important in case of perforated or fractured zones where loss of circulation can lead to congestion and difficulties in the drilling process.

- **Stabilization of Well Walls**

  Increased viscosity can help stabilize borehole walls, preventing collapse and cavities in clay or soft formations. This reduces the risk of tool jamming and ensures wellbore integrity.
- **Improved Pressure Maintenance**

  Drilling fluids with increased viscosity provide better pressure maintenance in the well. This is especially important when drilling in high-pressure geological conditions, where maintaining stable pressure prevents potential issues.
- **Turbulence Control**

  Increased viscosity can help control turbulence in the drilling fluid flow. This can be useful in preventing the formation of eddies, drifts, or other unstable flows that can affect drilling efficiency.
- **Improving Additive Delivery Capabilities**

  Viscous drilling fluids generally retain and distribute additives more efficiently, which can be important for achieving certain drilling goals such as clay stabilization, hydrate prevention, etc. However, increased viscosity can also impact energy costs for circulation and other aspects of drilling. Therefore, choosing the optimal drilling fluid viscosity requires a compromise and must be tailored to the specific well conditions and drilling objectives.

Use of additives and inhibitors: The use of additives in drilling fluids, such as clay mineral inhibitors, can significantly improve control of formation stability and prevent various problems, especially those associated with turbulent flow. Key benefits include:

Preventing hydrate formation: Clay mineral inhibitors can help prevent the formation of clay hydrates, which can cause the tool to jam and hinder the drilling process. This is especially important in turbulent flow conditions where hydrates can form more quickly.

Reducing clay sedimentation: The addition of clay mineral inhibitors can reduce the tendency of clays to settle in the drill rig and on the borehole walls. This helps maintain a strong wellbore structure and prevents problems such as diameter reduction and clogging.

Formation stabilization: Clay mineral inhibitors can help stabilize clay formations by preventing them from being softened by the drilling fluid. This is important to keep the wellbore intact and prevent potential collapses.

Control of rheological properties: Additives can also be used to control the rheological properties of the drilling fluid, which helps ensure more stable fluid flow in turbulent conditions.

Corrosion prevention: Some clay mineral inhibitors may also have properties that help prevent corrosion of equipment in contact with drilling fluid.

It is important to note that the selection and use of additives must be tailored to the specific geological conditions and requirements of a particular drilling task. The optimal drilling fluid formula may vary depending on soil type, hole depth, and other factors.

Real-time monitoring: The use of measurement systems while drilling to monitor parameters in real time is a key aspect of modern drilling operations. This practice allows operators to quickly respond to changing conditions and adjust drilling parameters to optimize the process. Below are some basic aspects and explanations:

Instant analysis of well conditions: Measurement systems provide instantaneous data on various well parameters such as pressure, temperature, tool run rate, and other characteristics. This data offers operators a clear understanding of current conditions.

Optimization of drilling parameters: Based on real-time data, operators can optimize drilling parameters such as trip rate, bottom pressure, drill bit RPM, and others. This helps maintain efficient and safe operations.

Preventing problems and urgent situations: Rapid monitoring and response to changing conditions can help prevent issues such as tool jamming, hole failure, dynamic pressure build-up, and other undesirable scenarios.

Adaptation to geological changes: Geological formation parameters can change as drilling progresses. Measurement systems enable operators to immediately adapt to such changes by modifying drilling according to new data.

Controlling the rheological properties of drilling fluid: Monitoring drilling fluid rheological properties (viscosity, density, etc.) allows operators to monitor and optimize drilling fluid properties in real time, which is crucial for maintaining drilling stability and efficiency.

Reducing risks and increasing safety: Measurement systems reduce the risk of accidents and improve the overall safety of drilling operations by providing operators with accurate data to make informed decisions.

The use of real-time measurement systems enables quick and efficient management the drilling process, boosting productivity and minimizing the risks of potential negative scenarios.

Turbulent fluid flow in an annular space is a complex dynamic system. Effective drilling control under such conditions requires careful analysis and optimization of parameters.

Analytical approach to drilling tool movement in wellbores: pressure balance and kinematics

Solution of the issue

Based on Figure 3, we derive an equation for the pressure balance during the movement of the drilling tool in the well, taking into account the stability of the rocks in the wellbore

$$P_0 + P_u + \Delta P \leq \sigma \tag{1}$$

where:

P_0 – hydrostatic pressure [Pa]

$P_0 = \gamma H$,

γ – specific gravity of the drilling fluid [N/m^3],

H – well depth [m],

P_u – inertial pressure component [Pa]

$$P_u = \frac{P_0}{g} \cdot \frac{du}{dt}$$

u – fluid speed in the annular space [m/s],

t – descent time [s],

g – free fall acceleration [m/s^2],

ΔP – pressure drop across the annular space, determined by the Darcy-Weisbach formula [Pa]

$$\Delta P = \gamma H \frac{\lambda}{2g(D-d)} u^2 = P_0 \frac{\lambda}{2g(D-d)} u^2$$

λ – coefficient of hydraulic resistance in the annular space.

Clearly, we are describing a simplification in the calculations of hydraulic resistance in the case of turbulent fluid flow in an annular space. The assumption of an almost constant value of the hydraulic resistance coefficient $\lambda = 0.0275$ in turbulent flow simplifies mathematical models and facilitates engineering calculations (Faradzhev and Aliyev, 1986; Chen, 2014). This approach is valid when the Reynolds numbers in a turbulent flow remain in a relatively narrow range, where variations in the hydraulic drag coefficient are negligible. Such simplifications are common in engineering practice to facilitate calculations and reduce model complexity. However, they may be limited by specific operating conditions and system characteristics.

In some cases, especially with a wider range of parameters, more accurate models and consideration of changing drag coefficients may be required for more accurate results.

D – well diameter [m],

d – outer diameter of drill pipes [m],

σ – ultimate strength of the formation for hydraulic fracturing [Pa].

Equation (1) reflects the pressure balance in the well taking into account the stability of the rock. It forms the basis for controlling drilling parameters and preventing potential issues such as hydraulic fracturing or wellbore wall collapse.

Considering the values P_0, P_u, ΔP equation (1) takes the form:

$$P_0 + \frac{P_0}{g} \cdot \frac{du}{dt} + P_0 \frac{\lambda}{2g(D-d)} u^2 \leq \sigma$$

or

$$\frac{1}{g} \cdot \frac{du}{dt} + \frac{\lambda}{2g(D-d)} u^2 \leq \frac{\sigma}{P_0} - 1 \tag{2}$$

This equation reflects the pressure balance taking into account the established parameters, and can be used to analyze and optimize drilling conditions to prevent hydraulic fracturing and ensure well stability.

The relationship between the fluid speed and the descent speed of the drilling tool is determined from the continuity condition:

$$\frac{\pi}{4}(D^2 - d^2)u = \frac{\pi}{4} d^2 v$$

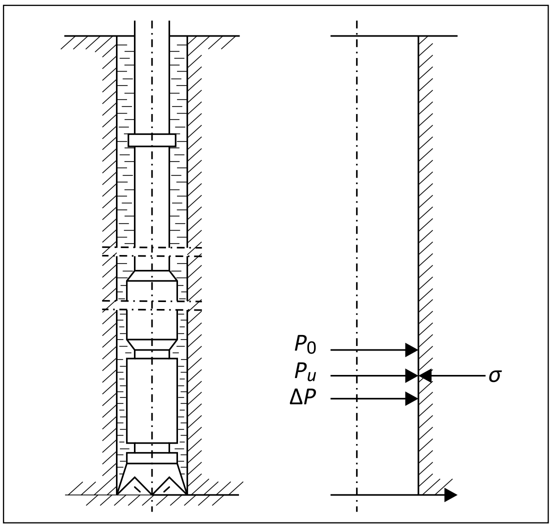

Figure 3. Calculation diagram of the acting pressures on the walls of the wellbore

Rysunek 3. Schemat obliczeniowy ciśnień działających na ściany otworu wiertniczego

from this

$$u = \frac{d^2}{D^2 - d^2} v$$

Substituting the value of u into equation (2) and taking into account the equal sign, it becomes

$$\frac{\boldsymbol{dv}}{\boldsymbol{dt}} = \boldsymbol{a}^2 - \boldsymbol{b}^2 \boldsymbol{v}^2 \tag{3}$$

where:

$$a^2 = \beta\left(\frac{\sigma}{P_0} - 1\right)$$

$$\beta = g\frac{D^2 - d^2}{d^2}$$

$$b^2 = \frac{\lambda}{2(D-d)} \frac{g}{\beta}$$

Dividing by variables, we get

$$\frac{dv}{a^2 - b^2 v^2} = dt \tag{4}$$

After integrating (4), we get

$$\frac{1}{2ab} \ln\left|\frac{a + bv}{a - bv}\right| = t + C$$

The integral constant is determined from the initial condition of running the tool into the well. With $t = 0$, $v = 0$ and $C = 0$, the equation becomes

$$\frac{1}{2ab} \ln\left|\frac{a + bv}{a - bv}\right| = t$$

After performing some algebraic transformations, we finally get

$$\boldsymbol{v} = \frac{\boldsymbol{a}}{\boldsymbol{b}} \mathbf{tanh}(\boldsymbol{abt}) \tag{5}$$

To determine the law of movement of the drilling tool into the well over the length of one candle, Equation (5) is used

$$v = \frac{ds}{dt} = \frac{a}{b} \tanh(abt)$$

From this

$$ds = vdt = \frac{a}{b} \tanh(abt)dt$$

After integrating the latter, we obtain

$$s = \frac{1}{b^2} \ln\left|\cosh(abt)\right| + C_1$$

Under the conditions $t = 0$, $s = 0$ we obtain $C_1 = 0$. Thus, the final equation for s is:

$$\boldsymbol{s} = \frac{1}{\boldsymbol{b}^2} \ln\left|\mathbf{cosh}(\boldsymbol{abt})\right| \tag{6}$$

Discussion of the solution

Using the obtained expressions (4), (5), and (6), graphs of acceleration, speed, and displacement of the drilling tool were constructed as functions of the descent time, considering corresponding values of σ/P_0, D and d (Figure 4–10). These graphs visualize how the acceleration, speed, and displacement of the drilling tool changes as a function of tripping time for various system parameters. Understanding the dynamics of the drill string in drilling mud is a key aspect of efficient and safe drilling operations. This analysis examines the effects of viscous media on drill string speed and movement, as well as the potential risks associated with these changes.

The line on the graph (Figure 4a) is trending downward, indicating that the W parameter decreases over the displayed time period.

The graph (Figure 4b) shows a curve that starts at the origin (0,0), initially increases sharply, indicating an increase in speed over time. After the initial rapid rise, the slope of the curve decreases, indicating that the speed continues to increase, but at a slower rate. Eventually, the curve begins to plateau, indicating that the speed approaches a constant value. This type of curve is typical of an object that accelerates initially but eventually reaches a terminal or constant velocity, often due to resistive forces such as friction or the drag of drilling fluid in the well, balancing the accelerating force.

The graph (Figure 4c) shows a steadily increasing curve, indicating that the distance, s, increases as a function of time, t. The nature of the curve suggests that the rate of increase in distance is not constant, but rather accelerates as the slope of the line increases over time.

Acceleration, speed, and movement are influenced by the gravity acting on the drill string as it is lowered into the hole (free run) and the resistance of the mud.

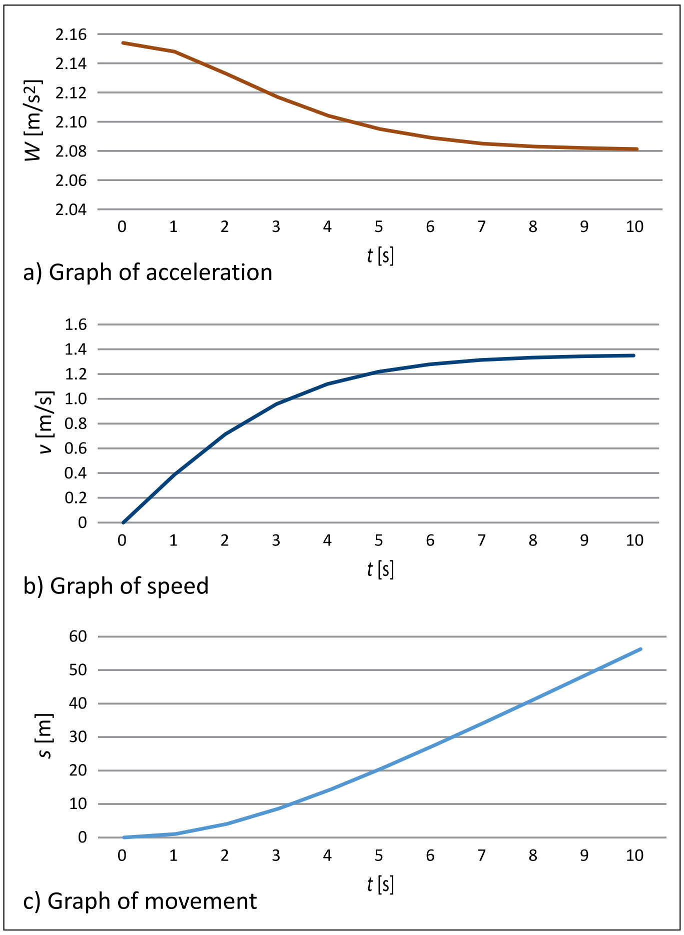

Figure 4. Graphs of acceleration, speed, and movement of the drilling tool depending on the descent time at values σ/P_0 = 1.08, D = 0.269 m and d = 0.140 m

Rysunek 4. Wykresy przyspieszenia, prędkości i ruchu narzędzia wiertniczego w zależności od czasu zapuszczania przy wartościach σ/P_0 = 1,08, D = 0,269 m i d = 0,140 m

Considering that at this stage 80% of the length of the candle is usually lowered into the well, in the case of (σ/p_0 = 1.08; D = 0.269 m; d = 0.14 m) it is determined from the displacement diagram in 6–7 seconds, the speed of the permissible value should not exceed 1.3 m/s. From this point on, the winch brake must be applied and the speed limited. Otherwise, there is a risk of hydraulic fracturing, which is compounded by the piston effect.

Effectively controlling the speed and movement of a drill string in mud requires precise monitoring and the application of appropriate control techniques. Understanding motion dynamics and responding promptly to changes in speed are essential for maintaining safe and efficient drilling operations.

Figure 5 is a graph showing the relationship between two variables: W (on the y-axis) measured in m/s^2 and t (on the x-axis) measured in seconds. The graph's title indicates that it is related to a dimensionless parameter σ/p_0 = 1.08, where σ and p_0 are likely specific parameters relevant to the context of the data.

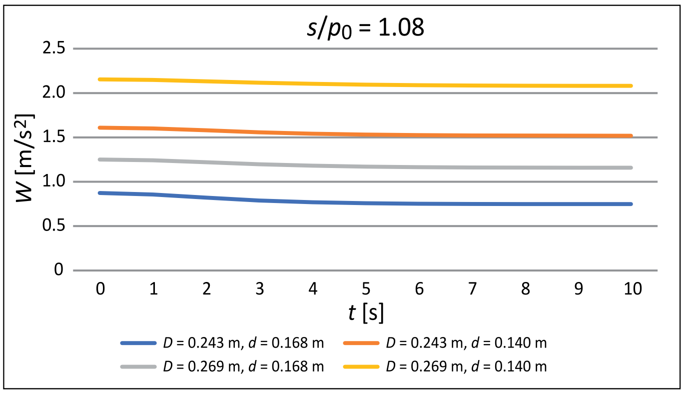

Figure 5. Graph of acceleration of the drilling tool depending on the descent time at the corresponding values σ/P_0 =1.08, D and d

Rysunek 5. Wykres przyspieszenia narzędzia wiertniczego w zależności od czasu zapuszczania przy odpowiednich wartościach σ/P_0 =1,08, D i d

The graph includes four lines, each representing a different scenario or dataset:

1. The blue line indicates the relationship for D = 0.243 m and d = 0.168 m.
2. The grey line represents D = 0.269 m with the same d = 0.168 m.
3. The orange line shows the relationship for D = 0.243 m but with a smaller d = 0.140 m.
4. The yellow line is for D = 0.269 m and d = 0.140 m.

All lines appear relatively flat, suggesting that W does not change much over time t for any given scenario. The differences in W values likely result from the variations in D and d, possibly derived from simulations. The exact nature of W, D and d would depend on the specific scientific or engineering context in which they are used.

Figures 6–9 show graphs plotting velocity (v, in meters per second) on the y-axis against time (t, in seconds) on the x-axis. There are five lines, each representing different ratios of a variable, possibly density or some other related factor, as indicated by the values (1.01, 1.02, 1.05, 1.08, and 1.1) next to the line markers. Each line likely represents a dataset or an experimental condition where that ratio is a significant parameter.

The lines show that the velocity increases over time for all conditions, but the rate of increase varies. The line with a ratio of 1.01 shows the slowest increase in velocity over time, while the line with a ratio of 1.1 shows the fastest increase. The graph suggests a saturation trend, where the velocity first increases rapidly and then levels off, indicating a possible approach to a maximum velocity or a limit due to the system constraints.

The color and shape of the markers distinguish the different ratios, providing a clear visual distinction for analysis or comparison. The trend suggests that the higher the ratio, the greater the initial acceleration and the higher the velocity that

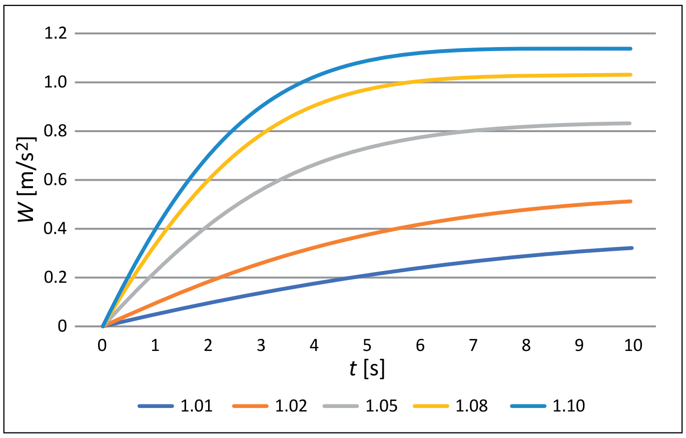

Figure 6. Graphs of the speed of the drilling tool depending on the descent time at $D = 0.269$ m, $d = 0.168$ m and the corresponding values of σ/P_0

Rysunek 6. Wykresy prędkości narzędzia wiertniczego w zależności od czasu zapuszczania przy $D = 0,269$ m, $d = 0,168$ m i odpowiednich wartościach σ/P_0

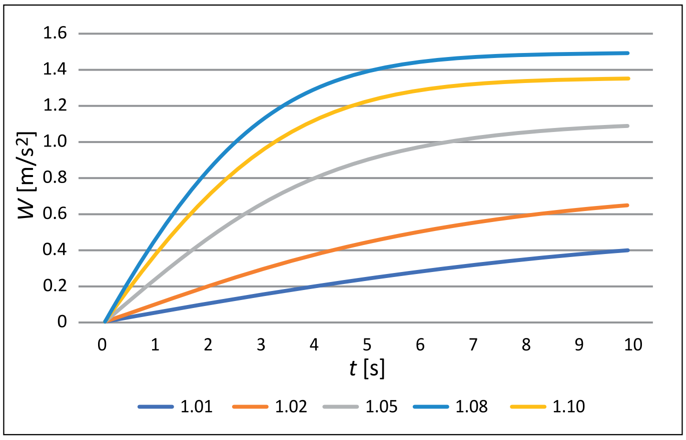

Figure 7. Graphs of the speed of the drilling tool depending on the descent time at $D = 0.269$ m, $d = 0.140$ m and the corresponding values of σ/P_0

Rysunek 7. Wykresy prędkości narzędzia wiertniczego w zależności od czasu zapuszczania przy $D = 0,269$ m, $d = 0,140$ m i odpowiednich wartościach σ/P_0

is reached within the 10-second period shown in the graph. The graph shows how the velocity of a drilling tool changes over time under these different conditions. The lines with higher values of σ/P_0 reach higher velocities faster, indicating that they encounter less resistance or are more efficient under these conditions. This type of information is critical for optimizing drilling operations to achieve efficient and safe drilling progress while managing the risk of hydraulic fracturing and other operational hazards.

The graph presented in Figure 10 appears to be a plot of displacement over time for a set of simulations where the parameter σ/ρ_0 is constant at a value of 1.08. The different lines represent trials with varying values of two parameters: *D* and *d*. Individual lines appear to represent:

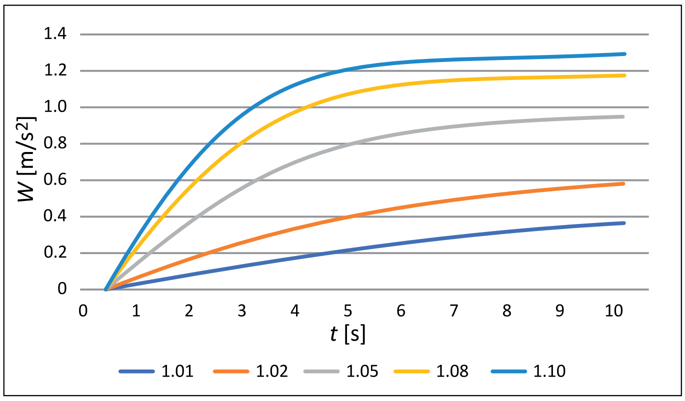

Figure 8. Graphs of the speed of the drilling tool depending on the descent time at $D = 0.243$ m, $d = 0.140$ m and the corresponding values of σ/P_0

Rysunek 8. Wykresy prędkości narzędzia wiertniczego w zależności od czasu zapuszczania przy $D = 0,243$ m, $d = 0,140$ m i odpowiednich wartościach σ/P_0

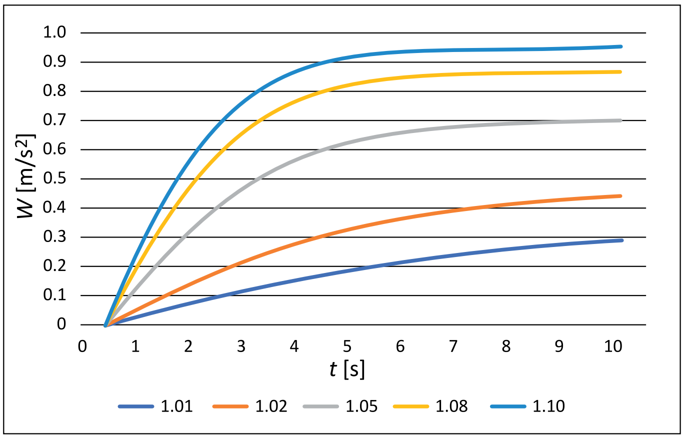

Figure 9. Graphs of the speed of the drilling tool depending on the descent time at $D = 0.243$ m, $d = 0.168$ m and the corresponding values of σ/P_0

Rysunek 9. Wykresy prędkości narzędzia wiertniczego w zależności od czasu zapuszczania przy $D = 0,243$ m, $d = 0,168$ m i odpowiednich wartościach σ/P_0

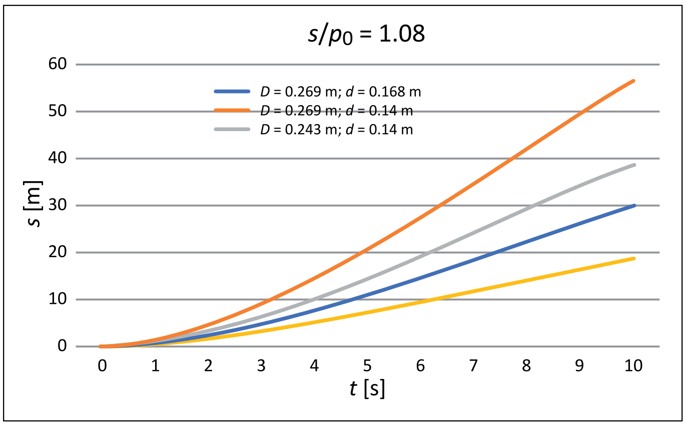

Figure 10. Graphs of the movement of the drilling tool depending on the running time at the corresponding values of σ/P_0, *D* and *d*

Rysunek 10. Wykresy ruchu narzędzia wiertniczego w zależności od czasu pracy przy odpowiednich wartościach σ/P_0, *D* i *d*

- The blue line: D = 0.269 m, d = 0.168 m,
- The orange line: D = 0.269 m, d = 0.140 m,
- The grey line: D = 0.243 m, d = 0.140 m,
- The yellow line: D = 0.243 m, d = 0.168 m

The graph shows that for a fixed value of σ/ρ_0, variations in D and d affect the displacement over time. Specifically, larger values of D and d result in a greater displacement for a given time. This observation is relevant in contexts such as fluid dynamics or mechanical engineering, where such parameters influence the behavior of a system or material over time.

The exact context would determine the precise interpretation of D, d, and σ/ρ_0.

Results

The importance of personnel training and qualifications cannot be underestimated in ensuring safety, efficiency, and successful innovation in the drilling process.

Drilling deep wells requires a comprehensive approach, including the careful selection of equipment, the application of the latest technologies, and a deep understanding of geological conditions. This approach optimizes operational efficiency and safety, ensuring the successful drilling of wells of significant size and depth.

Effective drilling in turbulent conditions requires a combination of technology, careful planning, and experience. Careful control of drilling fluid pressure, flow rate control, use of viscous drilling fluids, application of additives, and real-time monitoring all contribute to safety and efficiency in challenging drilling conditions.

The analytical approach presented in the article provides equations for understanding the balance of pressure and movement of drilling tools in turbulent conditions. These analytical tools enable engineers and drilling professionals to make accurate calculations and perform drilling operations efficiently.

In conclusion, fast lifting and lowering speeds, powerful lifting capacity, and integrated control systems are critical elements in improving the efficiency and safety of deep well drilling operations. The application of technological innovations and equipment optimization not only enhances productivity but also ensures adherence to high safety standards in the demanding conditions of deep well drilling.

The control algorithms developed enable the determination of the maximum safe rate of descent, taking into account the stability of the wellbore, depending on the well design, drill string and drilling fluid parameters.

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